Molten Salt vs. Liquid Sodium Receiver Selection Using the Analytic Hierarchy Process

Craig Turchi, PhD craig.turchi@nrel.gov
Thermal Energy Science & Technologies Group
National Renewable Energy Laboratory

Cara Libby, Electric Power Research Institute
Joe Coventry and John Pye, Australian National University

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Overview

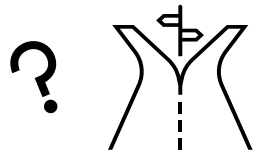
- *Gen3 Liquid Pathway* project seeks to demonstrate potential of chloride-based molten salt for energy storage at > 700°C.
- Chloride salt's high freeze point and poor thermal conductivity are challenges for use in a solar receiver.
- Project choose to evaluate liquid-metal sodium as an alternative receiver heat transfer fluid via a structured analytic hierarchy process.

Sandia National Laboratories

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

ASTRI
Australian Solar Thermal Research Institute

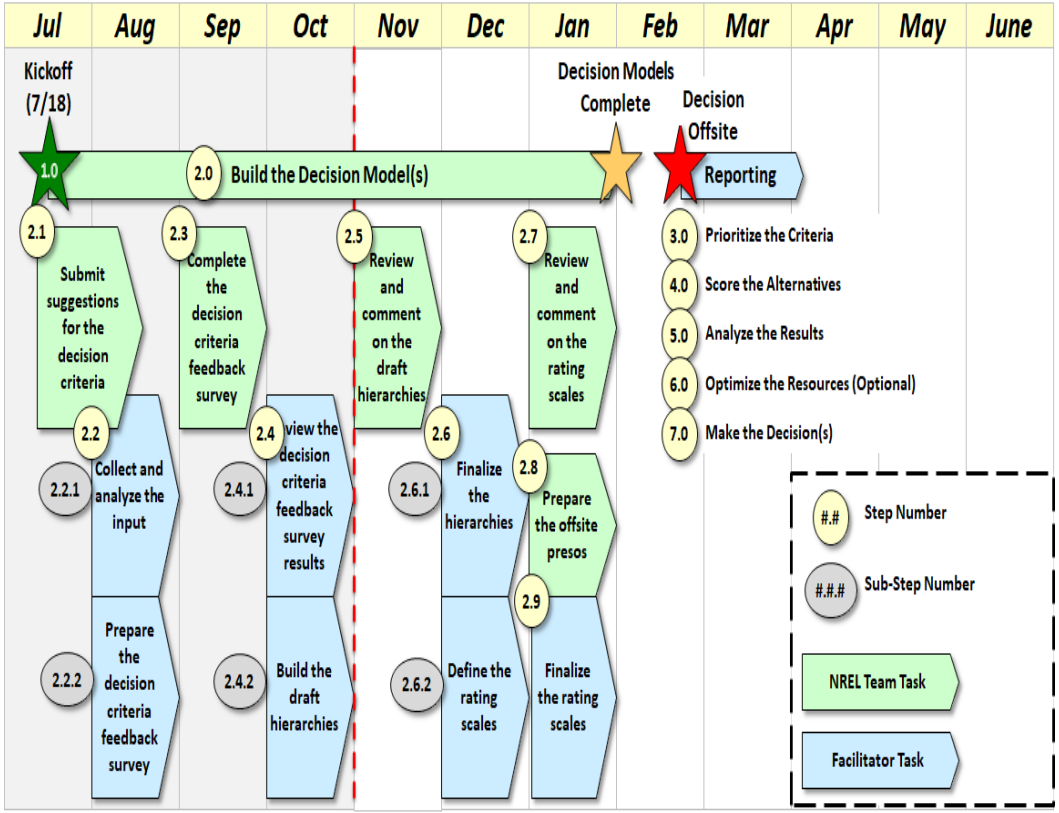
Analytic Hierarchy Process (AHP)



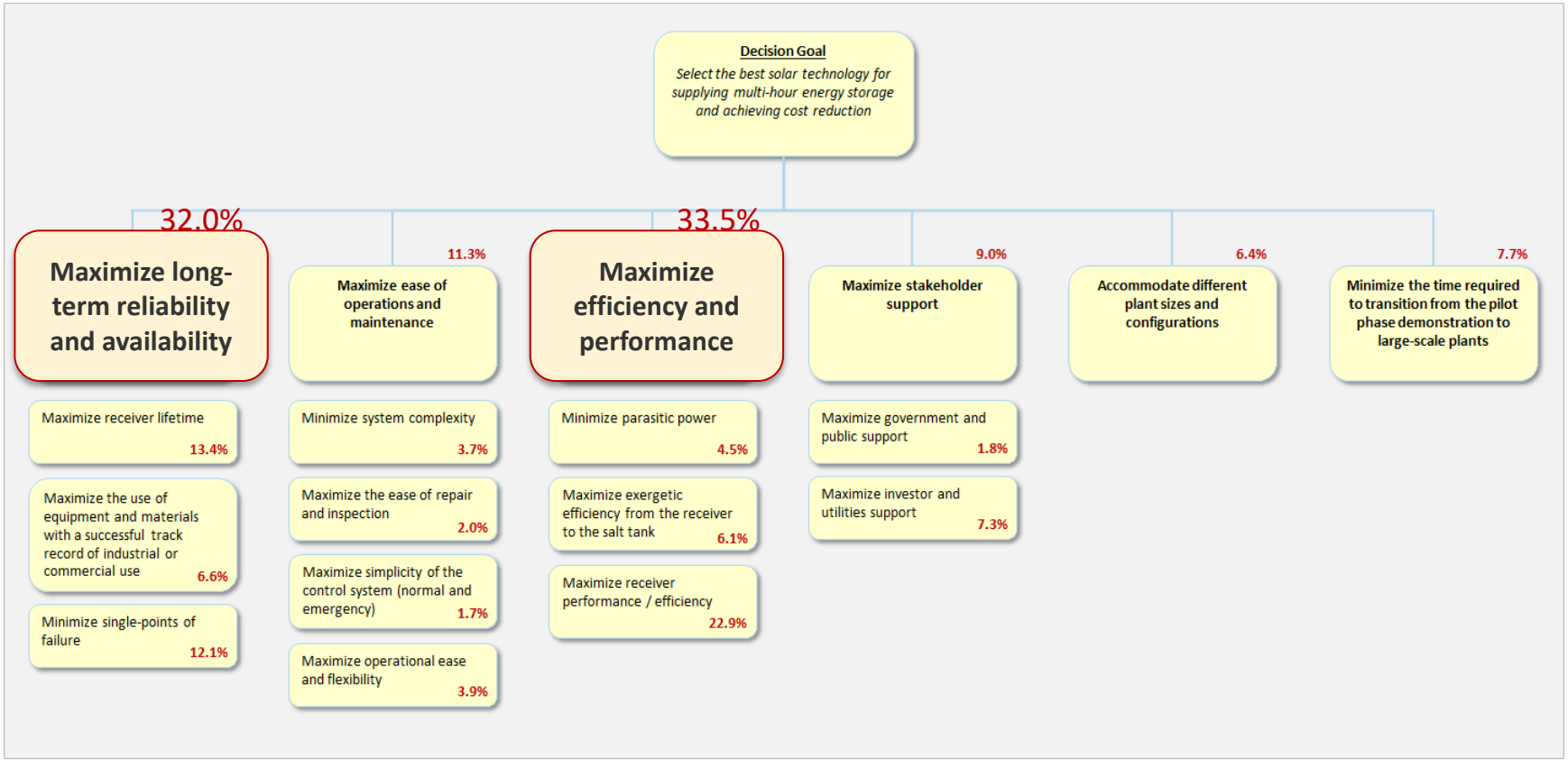
- Decision-making process developed in the 1990s to help work through complicated prioritization scenarios; widely used in the military, government, private sector, and academia.
- Encourages decisions based on knowledge that supports the decision-making process, rather than intuition.
- Simplifies the process by comparing two criteria at a time (i.e., pairwise comparisons) to determine which is more important with respect to the decision goal.
- Employs a multi-level (hierarchical) structure centered around an objective, weighted criteria, and alternatives.
  - For each criterion, the options are compared to one another in a series of pairwise comparisons.
  - With accurately weighted decision criteria in-place, the feasible alternatives can then be evaluated and scored against each criterion in a systematic fashion.
  - The result is a ranked order list of alternatives that summarizes the scoring team's knowledge and wisdom.
- AHP provides the ability to compare relative benefits and risks of alternatives instead of simply identifying a single top-performing option.

NREL's Process

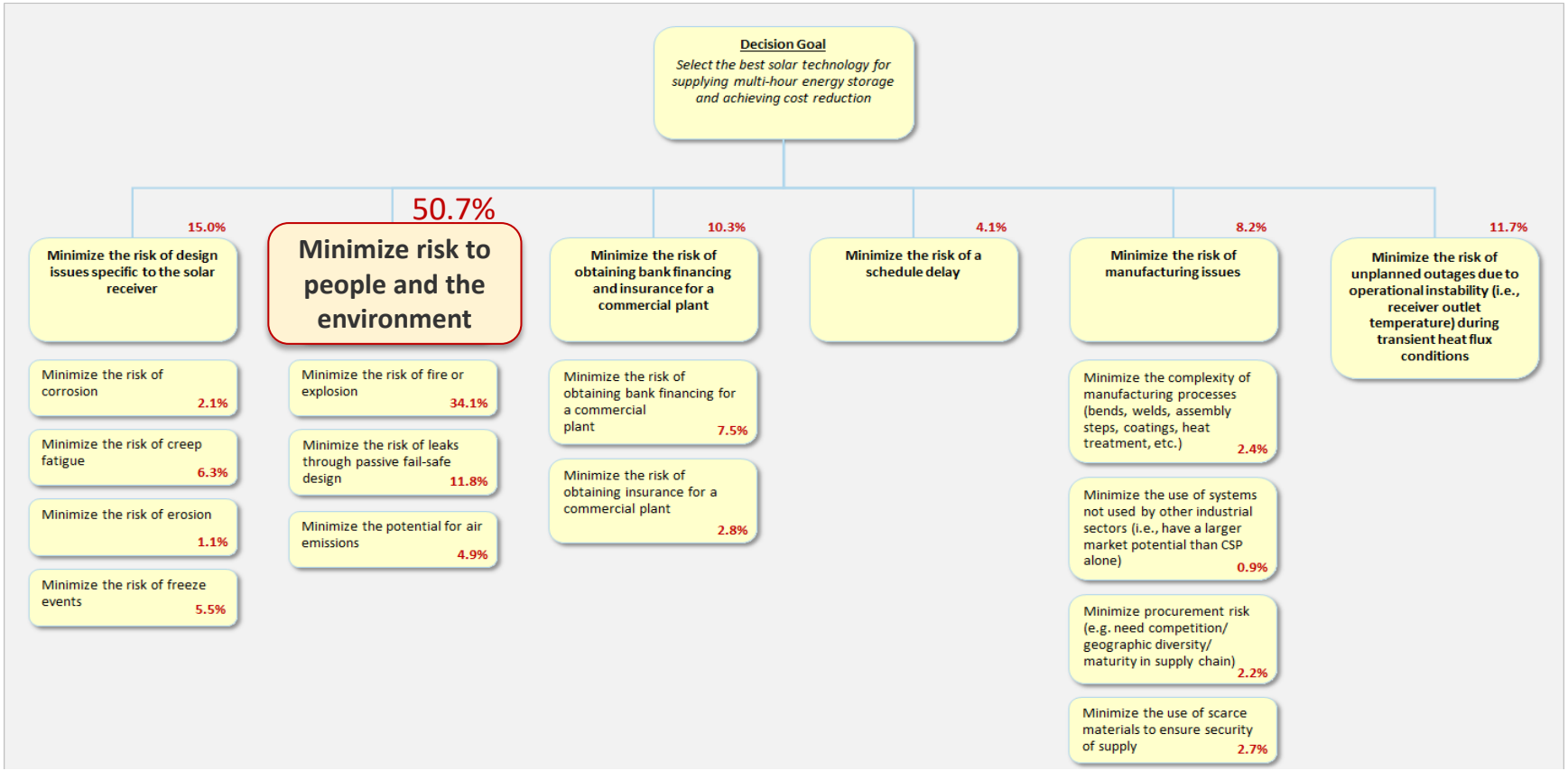
1. Define the decision team
2. Build the decision model
3. Prioritize the criteria
4. Score the alternatives
5. Analyze the results
6. Make the Decision



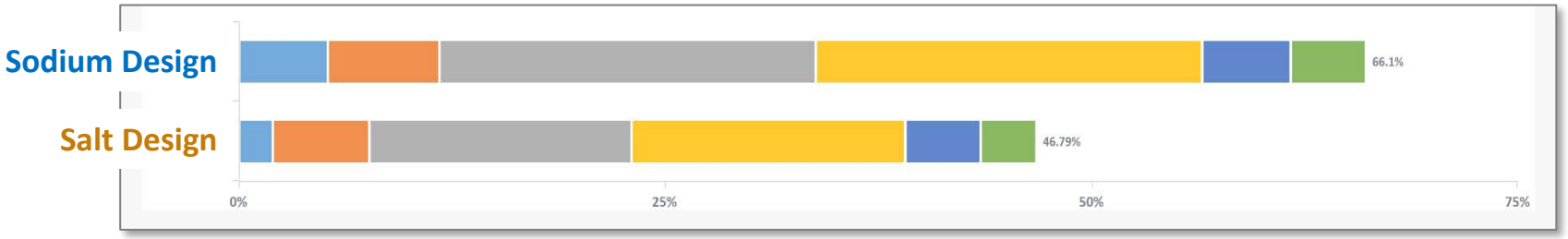
Weighted Benefit Criteria



Weighted Risk Criteria



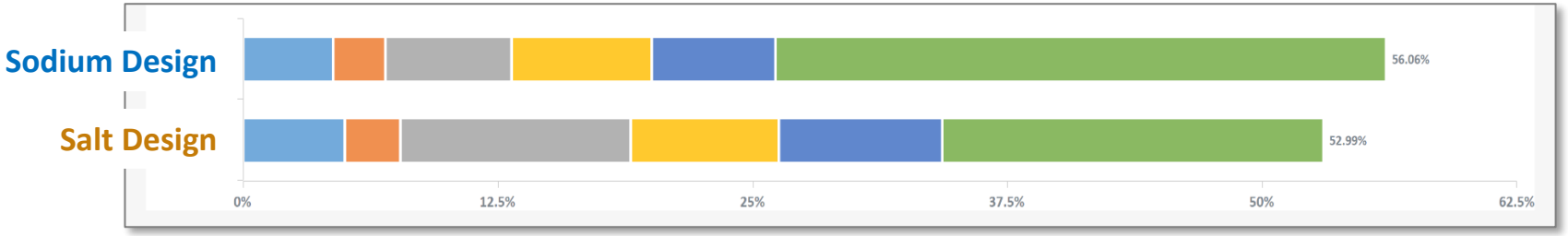
Benefit Scoring
(Higher Scores = Higher Benefit)



Criteria Legend

- Accommodate different plant sizes and configurations
- Maximize ease of operations and maintenance
- Maximize efficiency and performance
- Maximize long-term reliability and availability
- Maximize stakeholder support
- Minimize the time required to transition from the pilot phase demonstration to large-scale plants

Risk Scoring
(Higher Scores = Higher Risk)



Criteria Legend

- Minimize the risk of manufacturing issues
- Minimize the risk of a schedule delay
- Minimize the risk of design issues specific to the solar receiver
- Minimize the risk of obtaining bank financing and insurance for a commercial plant
- Minimize the risk of unplanned outages due to operational instability
- Minimize the risk to people and the environment

LCOE Model Validation

Parameter	SAM	SolarTherm	Difference
Energy per year (MWhe)	**551,608**	**559,096.83**	**+1.36%**
Capacity factor (%)	**63.0**	**63.89**	**+0.89%**
LCOE ($/MWh)	**79.3**	**78.55**	**−0.95%**
Annual optical efficiency (%)	49.75	50.8	+1.05%
Annual solar to thermal efficiency (%)	38.38	38.1	−0.28%
Annual solar to electric efficiency (%)	16.78	17.2	+0.42%
Annual field thermal input (DNI) (MWht)	3,286,497.23	3,250,562.97	−1.09%
Annual receiver thermal input (MWht)	1,635,065.98	1,651,285.99	+0.99%
Annual receiver thermal output (MWht)	1,261,213.45	1,238,464.49	−1.80%
Annual parasitic consumption (MWhe)	36141.02	36641.77	+1.39%

- *SolarTherm* checked against SAM for the salt-receiver case
- Agreement within 2%
- *SolarTherm* then used for sodium vs. salt comparison

Summary and Decision

- Sodium case has 11% lower LCOE
- Benefit/Risk ratio:
  - Sodium = 1.19
  - Salt = 0.86

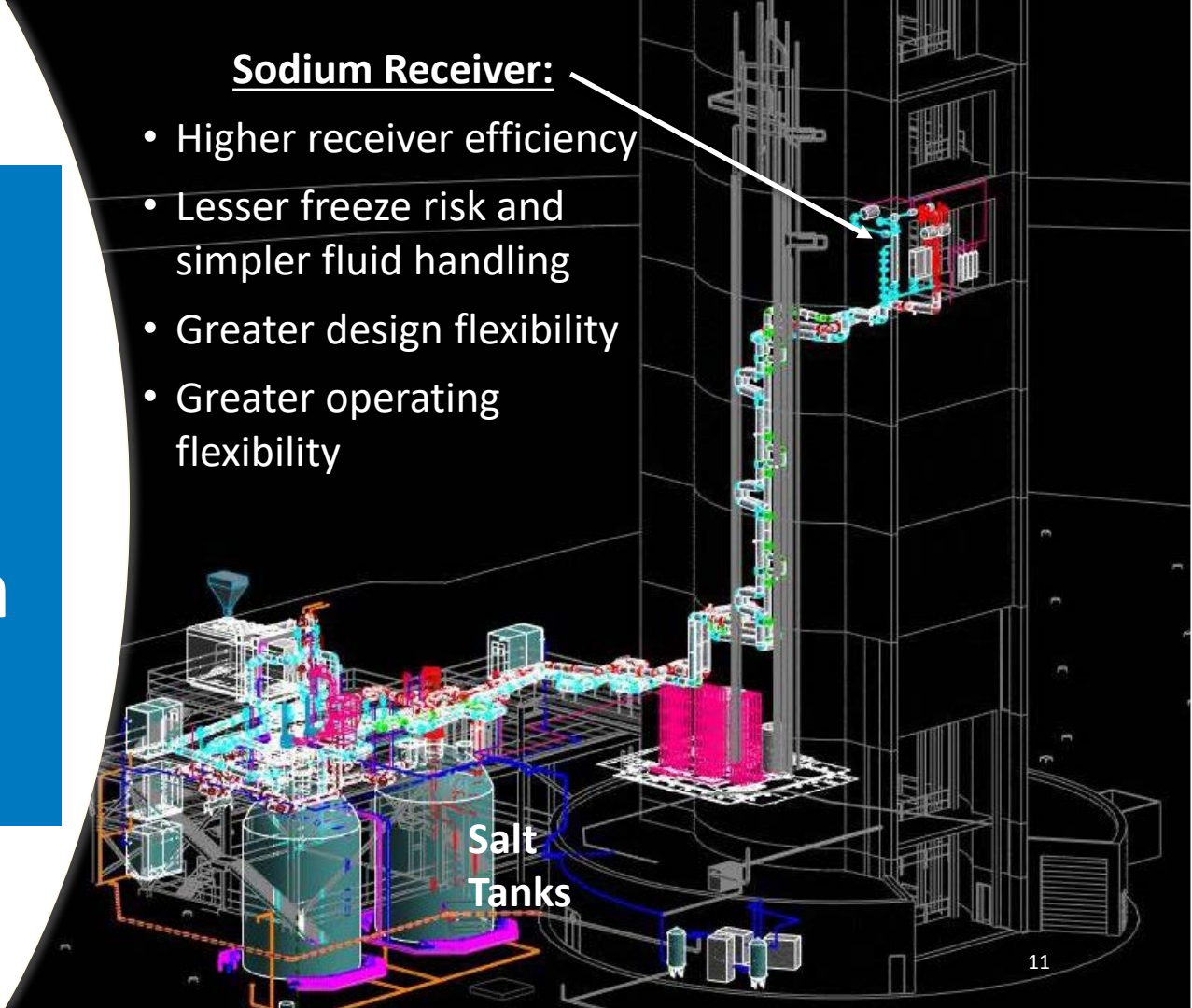
➢ ***Team selected the Sodium Receiver design***

Item	Sodium single-tower base case	Sodium single-tower improved*	Salt single-tower base case
Energy per year (MWh):	561959.88	540233.64	559096.83
Capacity factor (%):	64.21	74.24	63.89
LCOE ($/MWh):	72.69	69.6	78.55
Receiver thermal input at design point (MWt):	619.8	619.8	742
Receiver thermal output at design point (%):	543.2	543.2	587.6
Annual field efficiency (%)	53.5	51.6	50.8
Annual solar to thermal efficiency (%):	44.6	42.4	38.1
Annual solar to electric efficiency (%):	20.4	19.4	17.2
Power block gross rating at design point (MWe):	111	92.3	111
Power block efficiency at design point (%):	51	51	51
Full load hours of storage (h):	12	12	12
Storage capacity (kWht):	2611.8	2172.8	2611.8
Solar multiple:	2.5	3	2.7
Receiver diameter (m):	16	16	35
Receiver height (m):	24	24	20
Tower height (m):	175	175	175
Number of modules:	1	1	1
Number of heliostats:	6764	6764	8134
Number of heliostats per module:	6764	6764	8134
Single heliostat mirror area (m^2):	144	144	144
Total field area (m^2):	976553	976553	1174346

Proposed Integrated System Design

Sodium Receiver:

- Higher receiver efficiency
- Lesser freeze risk and simpler fluid handling
- Greater design flexibility
- Greater operating flexibility



Thank you!

www.nrel.gov

NREL/PR-5700-77819

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY